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The Appropriateness of the Poolability Assumption for Multiproduct Technologies: Evidence from the English Water and Sewerage Utilities [∗]

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Abstract. The empirical literature on the cost structure of multiproduct firms (e.g., public utilities providing in combination gas, water, and electricity) traditionally assumes a common technology across different products and stages of production, letting the issue of poolability unexplored. The appropriateness of this assumption is tested here by estimating a *General cost function* for samples of UK specialized and sewerage-diversified water utilities. The results show the existence of both aggregate scale economies and diseconomies of scope; more interestingly, the hypothesis that the two groups of water companies share the same technological parameters is rejected. Given the implications of this finding in terms of optimal industry configuration and possible restructuring policies (e.g., mergers and/or divestitures), our test suggests caution in pooling samples when undertaking empirical studies on data which refer to multiproduct technologies.

Keywords: Multiproduct technologies; Water and sewerage utilities; Poolability; General cost function

JEL codes: C52; C81; D24; L52 ; L95

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1. Introduction

The empirical literature studying the cost structure of firms initially focused on single product-single stage technologies (see, for example, Christensen and Greene, 1976, for electricity generation, and Tsionas and Loizides, 2001, for the railways industry). In subsequent developments, cost functions were allowed to accommodate for:

- multiple outputs (see, for example, Shin and Ying, 1992, and Christodoulopoulos, 1995, for the telecommunications industry), in order to investigate the presence and the extent of *multi-product* (or horizontal) scope economies;
- multiple production stages, with the aim of measuring *multi-stage* (or vertical) scope economies (see, for instance, Kaserman and Mayo, 1991, for electricity generation and distribution).

Finally, starting from the seminal work of Ivaldi and McCullough (2001), who estimated in the context of the US railways industry a cost function with three outputs at the downstream stage and one output at the upstream stage, scholars are now refining methodologies which, being capable to cope with multi product and multi-stage technologies, are particularly apt to investigate simultaneously on the presence of both scope and vertical integration interdependencies.

The above cited studies addressed some very important policy issues, such as the optimal organization of network industries which have been recently invested by deregulation and liberalization waves. For instance, the finding of the exhaustion of scale economies beyond a certain size threshold for telecommunications firms suggested the breakdown of State-owned monopolies in order to promote more competition. To take another example, the empirical finding of the presence of vertical integration economies in the electricity industry is not judged sufficient to counterbalance the efficiency gains which are expected to emerge from increased competition, so that a deverticalization process is often advocated as an effective policy to contrast the dominant position of incumbents. In a similar vein, the existence and the extent of scope economies for multi-utilities operating in gas, water and electricity services is a fundamental prerequisite for the policy debate about the unbundling of integrated operators into separate specialized entities.

In order to address the above issues, the use of an integrated approach (Weninger, 2003; Piacenza and Vannoni, 2009), which specifies a shared empirical multiproduct cost function in which diversified and specialized firm data are pooled in order to estimate function's unknown parameters, can be extremely useful. However, it relies on the maintained hypothesis of the existence of common structural properties across stages of production and, for each stage, across different products, a key assumption which can be too restrictive and may not be supported by empirical data. Rather surprisingly, but similarly to what happens in other areas of empirical analysis, the issue of poolability has been largely unexplored in the literature (see, for instance, Kapetanios, 2006). Electric utilities which are only active in the generation phase have been supposed to have the same production function of vertically integrated firms and pure distributors (Fraquelli *et al*., 2005). Similarly, multi-utilities active at different degrees in the gas, electricity and water sectors have been hypothesized to share the same technology (Fraquelli *et al*., 2004; Farsi and Filippini, 2009).

The problem of heterogeneity between sub-samples of firms has been treated by introducing fixed-effects in regressions, by adopting panel data methods that account for unobserved heterogeneity (such as the random parameter models used by Farsi, *et al*., 2008) or by comparing estimates from the pooled sample with results stemming from sub-samples of specialized firms. In this paper we propose to address the poolability issue by estimating a general model which includes different vectors of parameters for different sets of firms, and by performing statistical tests to verify the similarity or dissimilarity of such parameters vectors. For such a purpose, we use data on a sample of firms, including the ten large water and sewerage companies (WASCs) and all the smaller water only companies (WOCs), active in the English and Welsh water and sewerage sector over the period 1995-2005.

The remainder of the paper is organized as follows. Section 2 briefly revises the relevant literature, while section 3 presents and discusses our empirical methodology. Section 4 illustrates the key characteristics of dataset used in the present study. Section 5 presents the main results of our regressions, and Section 6 concludes.

2. Related literature

Previous work on the cost structure of the English and Welsh water and sewerage industry includes, among others, Stone & Webster Consultants (2004), who estimated both a total and a variable cost function using the translog specification and the generalized quadratic functional form. Their estimates, relative to the period 1993-2002, suggest that the joint production of water and sewerage services is likely to be characterized by diseconomies of scope. This result contrasts with that of Hunt and Lynk (1995), who, using data on the ten WASCs for the pre-privatization period, found evidence of cost complementarities in the joint production of water, sewerage and environmental services. More recently, Saal *et al.* (2007) estimated an input distance function for the ten WASCs over the period 1985-2000 and found evidence of decreasing returns to scale, a result that was later confirmed by Bottasso and Conti (2009a) who estimated a total cost function and found diseconomies of scale for the WASCs at the median sample point. Finally, Bottasso and Conti (2009b) estimated a variable cost function for the WOCs and found evidence of unexploited economies of output and customer density and small scale economies which were increasing with the level of population density.

Another relevant issue which has been investigated in the empirical literature is the link between regulation and productivity/efficiency developments in the English and Welsh water and sewerage industries. This issue has been considered, among the others, by Saal *et al*. (2007), who estimated a stochastic input distance function and found a constant level of inefficiency but positive technical change for the WASCs over the period 1985-2000 and by Bottasso and Conti (2009a, 2009b) who found a positive rate of technical change for both the WASCs and WOCs. For a discussion and comparisons between parametric and non parametric frontier models, see Murillo-Zamorano and Vega-Cervera (2001), for an application to electricity generation, and Resende (2008), for an application to US telecommunications.

3. Empirical strategy

The main goal of this paper is to contribute to the empirical literature on the technology of multi-product firms by analyzing the cost function of both WASCs and WOCs, through separate regressions as well as through a pooled specification which includes separate parameters vectors for the two sub-samples.

From a methodological point of view, we estimate a rather general functional form, i.e., the *General* specification of the *Composite* cost function model firstly introduced by Pulley and Braunstein (1992). The latter has been widely cited and recognized as particularly suitable for the analysis of multi-output firms, since it allows to better identify the existence of scope economies when a substantial fraction of the sample does not produce all outputs considered. In accordance to this, recent empirical research on different industries has shown that the *Composite* cost function model performs better with respect to other commonly used functional forms (e.g., the Translog model and the Generalized Quadratic model) and provides more precise estimates of cost economies measures (Piacenza and Vannoni, 2004). In spite of this fact, such specification has been rarely used as yet and has never been applied to the water and sewerage sector.

Let us assume the following *General* cost function specification (PB_G):

$$
\begin{aligned}
c(y;p)^{(\phi)} = \Bigg\{ \exp\Bigg[\Bigg(& \alpha_{WA} + \alpha_{WO} + \sum_i \alpha_{i_{WA}} y_{i_{WA}}{}^{(\pi_{WA})} + \sum_i \alpha_{i_{WO}} y_{i_{WO}}{}^{(\pi_{WO})} + \frac{1}{2}\sum_i\sum_j \alpha_{ij_{WA}} y_{i_{WA}}{}^{(\pi_{WA})} y_{j_{WA}}{}^{(\pi_{WA})} + \\
& \frac{1}{2}\sum_i\sum_j \alpha_{ij_{WO}} y_{i_{WO}}{}^{(\pi_{WO})} y_{j_{WO}}{}^{(\pi_{WO})} + \sum_i\sum_r \delta_{ir_{WA}} y_{i_{WA}}{}^{(\pi_{WA})} \ln p_r + \sum_i\sum_r \delta_{ir_{WO}} y_{i_{WO}}{}^{(\pi_{WO})} \ln p_r \Bigg)^{(\tau)}\Bigg] \\
& \cdot \exp\Bigg[\sum_r \beta_{r_{WA}} \ln p_{r_{WA}} + \sum_r \beta_{r_{WO}} \ln p_{r_{WO}} + \frac{1}{2}\sum_r\sum_l \beta_{rl_{WA}} \ln p_{r_{WA}} \ln p_{l_{WA}} + \frac{1}{2}\sum_r\sum_l \beta_{rl_{WO}} \ln p_{r_{WO}} \ln p_{l_{WO}} \Bigg]\Bigg\}^{(\phi)} \qquad [1]
\end{aligned}
$$

where $c(y;\, p)$ is the long-run cost of production, y_i and p_r refer to outputs and factor prices, *WA* and *WO* are two types of firms in which the sample has been partitioned ($y_{i_{WA}}$ and $p_{r_{WA}}$ record the values of the i^{th} output and of the price of the r^{th} input for WASCs and are zero for WOCs), the superscripts in parentheses ϕ, π_{WA}, π_{WO} and τ represent Box-Cox transformations. For example, in the case of π_{WA}, the Box-Cox transformation implies the following substitutions:

$$
y_i^{(\pi_{WA})} = (y_i^{\pi_{WA}} - 1)/\pi_{WA} \text{ for } \pi_{WA} \neq 0 \text{ and } y_i^{(\pi_{WA})} \to \ln y_i \text{ for } \pi_{WA} \to 0.
$$

By applying *Shephard's Lemma*, one can easily obtain the associated input cost-share equations:

$$
\begin{aligned}
S_r = \Bigg[& \alpha_{WA} + \alpha_{WO} + \sum_i \alpha_{i_{WA}} y_{i_{WA}}{}^{(\pi_{WA})} + \sum_i \alpha_{i_{WO}} y_{i_{WO}}{}^{(\pi_{WO})} + \frac{1}{2}\sum_i\sum_j \alpha_{ij_{WA}} y_{i_{WA}}{}^{(\pi_{WA})} y_{j_{WA}}{}^{(\pi_{WA})} + \\
& \frac{1}{2}\sum_i\sum_j \alpha_{ij_{WO}} y_{i_{WO}}{}^{(\pi_{WO})} y_{j_{WO}}{}^{(\pi_{WO})} + \sum_i\sum_r \delta_{ir_{WA}} y_{i_{WA}}{}^{(\pi_{WA})} \ln p_r + \sum_i\sum_r \delta_{ir_{WO}} y_{i_{WO}}{}^{(\pi_{WO})} \ln p_r \Bigg]^{\tau-1} \qquad [2] \\
& \cdot \left(\sum_i \delta_{ir_{WA}} y_{i_{WA}}{}^{(\pi_{WA})} + \sum_i \delta_{ir_{WO}} y_{i_{WO}}{}^{(\pi_{WO})} \right) + \beta_{r_{WA}} + \beta_{r_{WO}} + \sum_l \beta_{rl_{WA}} \ln p_{l_{WA}} + \sum_l \beta_{rl_{WO}} \ln p_{l_{WO}}
\end{aligned}
$$

Equation [1] embraces several of the most commonly used cost functions. The *Generalized Translog* (GT) and the *Standard Translog* (ST) models can be easily obtained by imposing the restrictions $\phi = 0$ and $\tau = 1$ (and $\pi_{WA} = \pi_{WO} = 0$ for the ST model). The *Composite* specification (PB_C) is a nested model in which $\pi_{WA} = \pi_{WO} = 1$ and $\tau = 0$, while the *Separable Quadratic* (SQ) functional form requires the further restrictions $\delta_{ir} = 0$ for all i and r.

Since the empirical results can have important implications for the policy design and the regulation of network industries, we stress the importance of considering different functional forms, so that the policy maker can rely on robust findings. For example, Christodoulopoulos (1995), while investigating the presence of natural monopoly conditions in the Greek telecommunications sector, compared the results coming from ST and GT multi-product cost function models and found noticeable differences between them. In a similar vein, Fraquelli *et al.* (2004) showed that measures of scale and scope economies where rather different across functional forms, with ST and GT specifications providing very unstable estimates when outputs were set near to zero.

In this paper we estimate the system [1]-[2] and carry out LR tests to select the model best fitting observed data. More interestingly, for the preferred model, the null hypothesis that there is a common parameter vector for *WA* and *WO* firms is tested again the alternative hypothesis that the parameters differ across sub-samples, by carrying out an LR test between a pooled specification versus an unrestricted one.

The fully unrestricted model (which allows for different parameters for WOCs and WASCs) has also been estimated including, as it is common in the literature, a set of control variables which takes into account firms' different operating conditions, such as the average pumping head, the proportion of water which is abstracted from rivers, the proportion of large users, the fraction of population receiving at least secondary sewage treatment. Furthermore, to take into account the quality improvements that took place over the sample period, we have checked that our main results are unaffected by the inclusion of quality adjusted outputs obtained by interacting output variables with quality indexes.[1]

4. Data

The dataset includes all the ten large water and sewerage companies (WASCs) and the smaller water only companies (WOCs) active in the English and Welsh water and sewerage sector over the period 1995-2005. Since the number of WOCs fell from 18 to 12 over the sample period, we end up with an unbalanced panel of 240 firm-year observations. When mergers took place between firms of similar size we considered the merged entity as a new firm entering the panel; on the other hand, if a merger involved companies with a considerable size differential we let the bigger survive. Finally, when a WOC was acquired by a WASC, we simply dropped the company from the sample. Table 1 presents descriptive statistics for the main variables considered in this paper, disaggregated for WASCs and WOCs.

Total costs (c) are the sum of labor, capital and other input costs, a residual category which includes materials, energy, services, etc. Outputs are the Megalitres/day of water delivered (y_w) and the equivalent sewerage population (y_s). Productive factors are labor (L), capital (K) and other inputs (O). Capital costs have been computed as the product of the capital stock and the price of

---

[1] Quality in the water sector was proxied by the index Q1, which is defined as the ratio of the average percentage of each WASC's water supply zones that are compliant with a set of key parameters, relative to the sample average in 1995/96. Quality in the sewerage sector was proxied by the index Q2, the percentage of sewerage treatment works not failing with respect to minimum sanitation standards. The estimates of the baseline models are presented below, while the results of the more complete specifications are available upon request.

capital, and deflated using the UK Construction Output Price Index. The capital stock has been proxied by the Modern Equivalent Asset estimation of replacement costs of net tangible assets, as reported in the regulatory accounts, but modified in order to take into account the periodic asset revaluations that occurred over the sample period. See Bottasso and Conti (2009a) for a detailed description of the methodology adopted. The price of labor (p_L) is given by the ratio of total employment expenses to the number of employees. The price of other inputs (p_O) is obtained by dividing residual expenses by the sum of the km of sewerage and water mains. The price of capital (p_K) has been calculated as the sum of the depreciation rate and the opportunity cost of capital capital, the latter computed as the actual nominal interest rate on ten years UK gilts (as a proxy for the risk-free rate of interest) plus the pre-tax regulatory premium less the tax benefit associated with debt financing (computed as the imputed tax-rate times company interest payments relative to the asset value). The regulatory premium is calculated on the basis of the assumptions adopted by Ofwat to set tariffs at the 1994 and 1999 price reviews and varies across companies (in particular, Ofwat's determinations allowed for a higher regulatory premium for the small WOCs). The summary statistics reported in Table 1 reveal that the WASCs are on average much larger than the WOCS; moreover, both within WASCs and WOCs there is a considerable variability in terms of size, as reflected by the large standard deviations for the two output measures.

The adoption of a cost function framework is particularly suitable when analyzing an industry characterized by the presence of several price regulated local monopolistic companies: in fact, given that both water and sewerage tariffs are set by the regulator and that operators are required to satisfy the demand, outputs can be safely considered exogenous. The facts that in the UK the use of metering is far from widespread, and water and sewerage tariffs are in practice a tax on the rateable values of properties, are reinforcing our assumption of outputs exogeneity. Furthermore, as the UK water and sewerage operators can be considered relatively small players in their respective input markets, also input prices can be considered exogenous.

5. Estimation results

All the specifications of the multi-output cost function are estimated jointly with the input cost-share equations via a non-linear GLS estimation (NLSUR, which is the nonlinear counterpart of the seemingly unrelated regression technique developed by Zellner, 1962). In our three-inputs case, to avoid singularity of the covariance matrix of residuals, only the equations for labor (S_L) and capital (S_K) were retained in the system. Before estimation, all variables were standardized on their respective sample average values.

A simple look at the estimates of Box-Cox parameters $\phi = 0.12$, $\tau = 0.08$, $\pi_{WA} = 0.47$ and $\pi_{WO} = 0.30$ suggests that the preferred model is the *General Composite* model (PB_G). More rigorously, the likelihood ratio statistics on the system log-likelihoods of the different models invariantly lead to the rejection of the (nested) PB_C, GT, ST and SQ models. Given the system log-likelihoods of the four restricted models L_r, with *r* alternatively being PB_C ($L_{PB_C} = 1826.23$), GT ($L_{GT} = 1821.82$), ST ($L_{ST} = 1814.19$), SQ ($L_{SQ} = 1634.25$), and the system log-likelihood of the unrestricted model, ($L_{PB_G} = 1858.67$), each LR test reads as follows:

$$LR = 2\cdot[L_{PB_G} - L_r] \qquad [3]$$

The statistics is always positive, as the unrestricted model PB_G must always have the larger likelihood, and it is asymptotically distributed as a Chi-square (χ^2) under the null hypothesis H_0 of the validity of the restricted model, with degree of freedoms corresponding to the number of tested restrictions. The tests, which are reported at the bottom of Table 2, are clearly in favor of the PB_G specification.

Turning now to the key issue of poolability which is the main focus of this paper, we can reject the null hypothesis H_0 that the parameters are invariant to the type of firm. A close inspection at the estimates reported in the two columns of Table 2, in fact, reveals some remarkable differences. This is confirmed by the LR test, that compares the log-likelihood of the general model [1] with the one resulting from a restricted specification in which the cost function parameters are undifferentiated for WASCs and WOCs (L_{COMMON}). The LR test is:

$$LR = 2\cdot[L_{PB_G} - L_{COMMON}] \qquad [4]$$

Comparing its value (LR=65.982) with the critical value of the Chi-square statistics ($\chi^2_{(11)} = 19.675$) leads to reject H_0 and to retain the GENERAL SPECIFICATION.

The summary statistics show that the estimated models perform quite well, with a McElroy system R^2 which is beyond 94% for all specifications. Moreover, the models exhibit a good degree of satisfaction of both output and input price regularity conditions (at least for 94% of sample points). The estimates of cost elasticities with respect to the water output are 0.40 for WASCs and 0.86 for WOCs, while the cost elasticity with respect to the sewerage output is 0.41. The estimated cost shares are 0.04 for labor and 0.87 for capital for WASCs (0.09 and 0.80 for WOCs), figures which are very close to the descriptive statistics reported in Table 1.

For the average WASC firm, global scale economies and scope economies are respectively *SE* = 1.23, and *SC* = -0.27, where:

$$SE(y;p) = 1/\sum_i \varepsilon_{cy_i} \qquad [5]$$

$$SC(y;p) = \left[c(y_w,0;p) + c(0,y_s;p) - c(y_w,y_s;p)\right] / c(y_w,y_s;p) \qquad [6]$$

highlighting that there are increasing returns to scale and that costs of diversified firms are higher than the sum of costs of two utilities specialised in the water and in the sewerage sector, respectively. This latter result has important implications in terms of optimal industry configuration; in particular it suggests that in some European countries, such as Italy and UK, the existence of integrated water and sewerage companies may not be justified on the grounds of cost savings arguments, and therefore a better resource allocation could be achieved through regulatory policies promoting the separation between water and sewerage services. Similar results on scope economies between water and sewerage services have been found by Stone and Webster (2004).

Tables 2 and 4 show that the results for the restricted model are qualitatively similar and point towards the presence of diseconomies of scope and weak increasing returns to scale. However, there are non trivial differences as far as the estimated cost shares and the measures of scale and scope economies are concerned. We have run also separate regressions for WASCs and WOCs, whose results are reported in Tables 3 and 4, which confirm quite sizeable differences in cost function parameters, cost shares and cost economies between the two types of firms. For a clear and meaningful comparison, notice that WOCs firms are only active in the water sector and are smaller than WASCs, which implies that the point of approximation at which scale and scope economies are computed refer to utilities of a smaller size for the former and of a larger size for the latter.

6. Conclusions

This paper analyses the cost structure of a sample of utilities active in the English and Welsh water and sewerage industry. From a methodological standpoint, we use the general specification of the *Composite* cost function model, which is tested against other popular functional forms, on the one hand, and we test the hypothesis that WASCs and WOCs share the same technology, on the other hand. The results of the LR tests confirm the merits of the PB-type cost functions and show for the average firm the existence of both aggregate scale economies and scope diseconomies. More interestingly, the hypothesis that the two groups of firms share the same technology is rejected (LR = 65.982, which is well above the critical value $\chi^2_{(11)}$ = 19.675).

While the pooling of specialized and (horizontally and/or vertically) diversified firms is a common practice in empirical investigations on cost structure and efficiency assessment of multi-product utilities, the presence of heterogeneity among utilities suggests that a cost function with technological coefficients which are invariant across sub-samples of firms might be inadequate for a reliable analysis of cost properties of network utilities**.** The results of our simple exercise suggest to adopt a cautious approach which duly takes into account the possibility to relying on different functional forms and, for the preferred specification, to have a separate set of parameters for different sub-samples.

This issue is particularly relevant for the analysis of public utility industries undergoing intense restructuring processes through mergers and/or divestitures policies (e.g., energy, railways, as well as water distribution utilities all around continental Europe), given the widespread welfare impact associated with these regulatory interventions. For instance, considering the UK water sector, some issues at stake are:

- the consolidation of the industry, in order to increase the volumes and the scale of production;
- the unbundling and/or breakdown of water and sewerage activities;
- the economic assessment of mergers and acquisitions (especially between WASCs and WOCs), and the extension of local monopolies to new neighbouring areas;
- the vertical integration or separation between distribution and upstream production phases.

Our analysis provides hints and suggestions for all the above issues except the last one, and is in favour of a further consolidation of the industry, a process which should be however accompanied with the separation of water and sewerage activities.

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Table 1. Descriptive statistics

Variable	Full sample		WASCs		WOCs	
	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev
Volume water (y_w)	529.6	573.6	1045.5	577.4	185.7	175.2
Sewerage pop (y_s)	2497.2	3913.3	6242.9	3859.6	0	0
Total costs (c)	855.3	1130.8	1975.8	1043.3	108.4	97.0
Labour share (S_L)	0.064	0.024	0.043	0.011	0.078	0.020
Capital share (S_K)	0.827	0.048	0.877	0.024	0.794	0.027
Other inputs share (S_O)	0.109	0.032	0.080	0.017	0.128	0.023
Labour price (p_L)	25.6	4.4	27.3	4.9	24.5	3.6
Capital price (p_K)	10.3	1.5	9.4	1.0	10.9	1.4
Other inputs price (p_O)	0.0030	0.0008	0.0026	0.0006	0.0032	0.0008
Observations	240		96		144	

Volume water: ML per day of water delivered
Sewerage population: thousands of equivalent people
Total costs: thousands of UK £
Price labour: thousands of UK £
Price capital: percentage ratio
Price other inputs: thousands of UK £ / thousands Km of water and sewerage mains

Table 2. NLSUR estimates of the *General* cost function [1] - Pooled sample

Regressor[a]	POOLED SAMPLE (GENERAL SPECIFICATION)		POOLED SAMPLE (COMMON SPECIFICATION)	
	Coefficient	S.E.	Coefficient	S.E.
$Box\text{-}Cox\,\phi$	0.119***	(0.024)	0.142***	(0.021)
$Box\text{-}Cox\,\pi_{WA}$	0.473	(1.144)	0.806***	(0.088)
$Box\text{-}Cox\,\pi_{WO}$	0.298**	(0.120)		
$Box\text{-}Cox\,\tau$	0.083	(0.111)	-0.155	(0.126)
$Constant_{WA}$	1.489***	(0.185)	1.334***	(0.057)
$Constant_{WO}$	1.746	(2.058)		
$y_{w\,WA}$	0.521**	(0.253)	0.650***	(0.121)
$y_{w\,WO}$	0.287***	(0.046)		
$y_{s\,WA}$	0.532***	(0.183)	0.593***	(0.080)
$y_w^2{}_{WA}$	0.071	(1.197)	0.035	(0.081)
$y_w^2{}_{WO}$	0.142***	(0.047)		
$y_s^2{}_{WA}$	-0.226	(0.833)	-0.308**	(0.150)
$y_w y_{s\,WA}$	0.252	(0.799)	0.284	(0.117)
$\ln p_{L\,WA}$	0.038***	(0.004)	0.039***	(0.002)
$\ln p_{L\,WO}$	0.086***	(0.007)		
$\ln p_{K\,WA}$	0.874***	(0.006)	0.875***	(0.003)
$\ln p_{K\,WO}$	0.798***	(0.007)		
$\ln p_L y_{w\,WA}$	0.008	(0.014)	0.007***	(0.001)
$\ln p_L y_{w\,WO}$	-0.001	(0.001)		
$\ln p_K y_{w\,WA}$	-0.025	(0.023)	-0.017***	(0.003)
$\ln p_K y_{w\,WO}$	0.000	(0.001)		
$\ln p_L y_{s\,WA}$	-0.008	(0.014)	-0.008***	(0.001)
$\ln p_K y_{s\,WA}$	0.026	(0.022)	0.018***	(0.003)
$\ln p_L \ln p_{K\,WA}$	-0.026**	(0.011)	-0.023***	(0.004)
$\ln p_L \ln p_{K\,WO}$	-0.021***	(0.006)		
$\ln p_L \ln p_{O\,WA}$	-0.003	(0.009)	-0.015***	(0.002)
$\ln p_L \ln p_{O\,WO}$	-0.028***	(0.003)		
$\ln p_O \ln p_{K\,WA}$	-0.039***	(0.013)	-0.050***	(0.005)
$\ln p_O \ln p_{K\,WO}$	-0.047***	(0.006)		
Observations	240		240	
System Log-likelihood	1858.670		1825.679	
McElroy system R^2	0.997		0.997	
LR test (PB_G vs. PB_C)	64.88***		-	
LR test (PB_G vs. GT)	73.70***		-	
LR test (PB_G vs. ST)	88.96***		-	
LR test (PB_G vs. SQ)	448.84***		-	
LR test (GENERAL vs. COMMON)	-		65.98***	

[a] Dependent variable: *c* = total cost of production. Levels of significance: ***1%,**5%,*10%.

Table 3. NLSUR estimates of the *General* cost function [1] - Separated samples

Regressor[a]	WASC SAMPLE (WA)		WOC SAMPLE (WO)	
	Coefficient	S.E.	Coefficient	S.E.
Box-Cox ϕ	-0.767***	(0.181)	0.009	(0.072)
Box-Cox π_{WA}	0.800***	(0.097)	-	-
Box-Cox π_{WO}	-	-	-0.112**	(0.057)
Box-Cox τ	-0.157	(1.652)	0.558***	(0.059)
Constant $_{WA}$	1.048***	(0.025)	-	-
Constant $_{WO}$	-	-	1.008***	(0.024)
$y_{w\,WA}$	0.540***	(0.169)	-	-
$y_{w\,WO}$	-	-	0.963***	(0.032)
$y_{s\,WA}$	0.332**	(0.144)	-	-
$y_w^2{}_{WA}$	-0.097	(0.677)	-	-
$y_w^2{}_{WO}$	-	-	0.463***	(0.032)
$y_s^2{}_{WA}$	-0.475	(0.760)	-	-
$y_w y_{s\,WA}$	0.312	(0.442)	-	-
$\ln p_{L\,WA}$	0.042***	(0.002)	-	-
$\ln p_{L\,WO}$	-	-	0.074***	(0.002)
$\ln p_{K\,WA}$	0.879***	(0.005)	-	-
$\ln p_{K\,WO}$	-	-	0.794***	(0.002)
$\ln p_L y_{w\,WA}$	0.003	(0.007)	-	-
$\ln p_L y_{w\,WO}$	-	-	-0.001*	(0.001)
$\ln p_K y_{w\,WA}$	-0.008	(0.018)	-	-
$\ln p_K y_{w\,WO}$	-	-	0.001	(0.001)
$\ln p_L y_{s\,WA}$	-0.006	(0.008)	-	-
$\ln p_K y_{s\,WA}$	0.014	(0.016)	-	-
$\ln p_L \mathrm{l\ n} p_{K\,WA}$	-0.018*	(0.010)	-	-
$\ln p_L \ln p_{K\,WO}$	-	-	-0.025***	(0.008)
$\ln p_L \ln p_{O\,WA}$	-0.007	(0.008)	-	-
$\ln p_L \ln p_{O\,WO}$	-	-	-0.028***	(0.004)
$\ln p_O \ln p_{K\,WA}$	-0.046**	(0.019)	-	-
$\ln p_O \ln p_{K\,WO}$	-	-	-0.039***	(0.006)
Observations	96		144	
System Log-likelihood	754.931		1115.02	
McElroy system R^2	0.942		0.951	

[a] Dependent variable: *c* = total cost of production. Levels of significance: ***1%,**5%,*10%.

Table 4. Cost properties estimates for pooled and separated samples (at the average values for outputs and input prices) [a]

	POOLED SAMPLE (GENERAL SPECIFICATION)	POOLED SAMPLE (COMMON SPECIFICATION)	WASC SAMPLE (WA)	WOC SAMPLE (WO)
Output elasticity				
$\varepsilon_{w\ WA}$	0.40 (0.21)	0.47 (0.07)	0.51 (0.15)	
$\varepsilon_{w\ WO}$	0.86 (0.08)			0.96 (0.03)
$\varepsilon_{s\ WA}$	0.41 (0.14)	0.42 (0.06)	0.31 (0.14)	
Economies of scale (SE) and scope (SC)				
$SE_{w,s\ WA}$	1.23 (0.22)	1.12 (0.06)	1.21 (0.07)	
$SE_{w\ WO}$	1.16 (0.10)			1.04 (0.03)
$SC_{w,s}$	-0.27 (1.02)	-0.34 (0.15)	-0.53 (0.66)	
Input cost-shares				
$S_{L\ WA}$	0.04 (0.00)	0.04 (0.00)	0.04 (0.01)	
$S_{L\ WO}$	0.09 (0.01)			0.07 (0.02)
$S_{K\ WA}$	0.87 (0.01)	0.88 (0.00)	0.88 (0.02)	
$S_{K\ WO}$	0.80 (0.01)			0.79 (0.03)

[a] Standard error in parenthesis.